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Ross Biro

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ABSTRACT:

As the quantity of information available on the Internet grows, locating a particular piece of information becomes more difficult. One possible solution is for a database of pointers to all available information to be maintained at a central site. Subject classifications for all the information could also be maintained in order to make searching possible. This paper describes one possible method of searching such an index. In particular a prototype browsing tool has been created using TCL[1]/TK[2] to demonstrate several possible features: rapidly scanning at any rank of the index, narrowing the index to any scope, regular-expression searching, and creation of a list of pointers answering to any set of index terms. The prototype browser is an easy-to-use independent X application designed for use in the Catalog of Repositories of the HPCC[3] Software Exchange.

Introduction

Terrabytes[4] of information await those willing to explore the Internet; however, locating a specific file or piece of information is often too time consuming to be useful. Attempts to categorize the major sources of information have added to what is available; often causing individual pieces of information to become lost in the crowd. For example, the Veronica[5] index to Gopher[6] contains approximately 380 million characters; querying Veronica with the search term "math"

[1] TCL, pronounced "tickle", is an acronym for tool command language, an interpretive programming language.

[2] TK is an X toolkit implemented in TCL.

[3] The HPCC (High Performance Computing and Communications) Program is a national initiative sponsored by several federal agencies (including DOC, DOD, DOE, NASA, and NIH) to secure US competitiveness in advanced computing and communication. The HPCC Software Exchange Project, to facilitate software development and reuse among HPCC workers, is managed by NASA in cooperation with the other HPCC agencies.

[4] A terrabyte is 2^{40} or approximately $1,000,000,000,000$ characters; enough to fill 1 billion typed pages.

[5] Veronica is an acronym for Very Easy Rodent-Oriented Net-wide Index to Computerized Archives, developed by Steve Foster and Fred Barrie at the University of Nevada

[6] Gopher is software following a simple protocol for burrowing through a TCP/IP Internet [AALMT].

returns approximately 200 entries, too many to be of use. However, searching for a more specific term such as "algebraic topology" returns nothing, even though the preprint archive at `hopf.math.purdue.edu` contains several papers related to algebraic topology.

Similar problems exist for other information providers on the Internet. For example, there are approximately 1000 anonymous ftp[7] servers indexed by Archie.[8] Each server contains different quantities and types of information; some of the larger servers such as `sunsite.unc.edu`[9] have several billion characters of information divided into thousands of files; the largest ftp servers contain more than a hundred thousand files. Archie indexes entries only by their file names, not contents, which makes locating a particular piece of information nearly impossible if you do not already know the name of a file that contains it.

Other information servers use various methods to make locating information easier. WAIS[10] indexes the contents of its files; however, one must know which of the hundreds of files indexed by WAIS to search in order to find a particular piece of information. The World Wide Web[11] uses hyper-text to help make locating information easier; however, there is no organized table of contents or index to make finding a particular piece of information easy. There are also many specialized databases,[12] many of which are not indexed. Some of the information providers on the Internet are effectively secret because there are few ways to advertise services. Hence it is often difficult to find information without already knowing where it is.

Currently the methods used for finding a particular piece of information on the Internet depend on what is known about it. Knowing the name of a file is often enough to locate it; however, the content of a file is seldom reflected in its

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[7] ftp is an abbreviation for File Transfer Protocol and is commonly used to transfer files across the Internet.

[8] Archie is an index, accessed via the Internet, of well known publicly accessible ftp servers around the world

[9] `sunsite.unc.edu` is an ftp server maintained by the University of North Carolina in Cooperation with Sun Microsystems Inc.

[10] WAIS is an acronym for Wide Area Information Server [K].

[11] World Wide Web (W3) is a wide-area hyper-media information service [BCP]

[12] For a more complete list of the information servers available on the Internet, see [Ke] and [Kr]

name. For example, a preprint of a scientific paper is often named after the authors; hence locating a preprint by author is simple, however locating one by title or content is nearly impossible. There is no consistent file-naming scheme to make finding the information easy.

To locate a file without knowing its name is difficult. WAIS or gopher may help, but only if a file or site to search is already known. However, many information sources are not indexed via WAIS or accessible via gopher, so WAIS and gopher do not often help one locate a particular piece of information. Currently the most reliable way of locating a piece of information is to guess plausible file names and search for them with Archie and Veronica.

Here is an example of a real world example of attempting to locate a program without knowing its name. How does one locate a program that strips the commands out of a postscript file and leaves just the text? Indeed, does such a program even exist? One method would be to use Archie to search for programs with names that describe what the program does, such as pstext or ps2text. A program named pstext does exist; however, it converts a text file to postscript; not what we are searching for. Searching for ps, ps2, or text returns too many matches to be useful. So one might try searching via WAIS. However, what WAIS file should one search? If the program is known to be at a particular ftp site, and that site is indexed via WAIS, locating the program should not be difficult. However, unless one knows where to look, WAIS will not be useful. Fortunately a large ftp site, `sunsite.unc.edu`, can be searched via WAIS. In this case a search of `sunsite` will locate the programs ps2ascii and ps2term, which will serve our purpose.

The problem of locating a particular file or piece of information on the Internet remains. One possible solution is the approach taken by the HPCC Software Exchange; which has constructed a prototype database containing pointers to a useful subset of the information available on the Internet, and indexes the database in a way similar to that of Archie or Veronica. This in itself does not provide any greater service than is available already; however, the information is also searchable via author, title, or abstract, and categorized by content using a hierarchical subject thesaurus. Such a thesaurus makes searching for information by content possible. A prototype database and thesaurus have already been created with more than 200 information servers indexed by subject.

To build the thesaurus, every piece of information provided needs to be categorized by content. For some specialized information servers, categorizing the server is enough; however, for large general archives individual files or directories may be classified separately. An example of an information server that has been categorized is GAMS.[13] GAMS appears in the prototype thesaurus under the category *MATHEMATICAL SCIENCE* in the sub-category *Mathematics* in the sub-sub-category *Analysis.* But since GAMS also contains program useful for geometrical problems, it appears under the sub-sub category *Geometry* also. Some of the software available via GAMS may also be useful to people interested in Behavioral Science. So GAMS also appears under the category *BEHAVIORAL SCIENCES* under the sub category *Measurement, Statistics, and Evaluation.* In all, GAMS appears twenty seven times in the prototype thesaurus.

Given that we have such a thesaurus, the question becomes how does one use it to find information. The purpose of the HPCC software exchange is to make locating information on the Internet not only possible but easy: a database and thesaurus are not enough. A tool to browse and search a thesaurus is also necessary. This document discusses the design and use of one such browsing tool, as well as pointing out directions for future enhancements. Although the source code for the prototype browsing tool has been made available, this should not be considered as documentation for the sample implementation, and the sample implementation should not be considered ready for use.

Thesaurus

Any tool designed to browse a thesaurus will be limited by the content and structure of the thesaurus. Hence in order to understand the browsing tool, we must first understand the thesaurus. The prototype thesaurus is hierarchically arranged by category; each top-rank category is a general term, which can have more specific sub-categories, and each sub-category may itself contains sub-categories, etc. A small part of the thesaurus is illustrated in Figure 1 where id codes (indicated by exclamation marks) are also included following the appropriate (sub-)categories.

[13] Guide to Available Mathematics Software (GAMS) is a database of mathematical software provided by the National Institute of Standards and Technology, which is equipped with a sophisticated subject index and browser of its own [BHK].

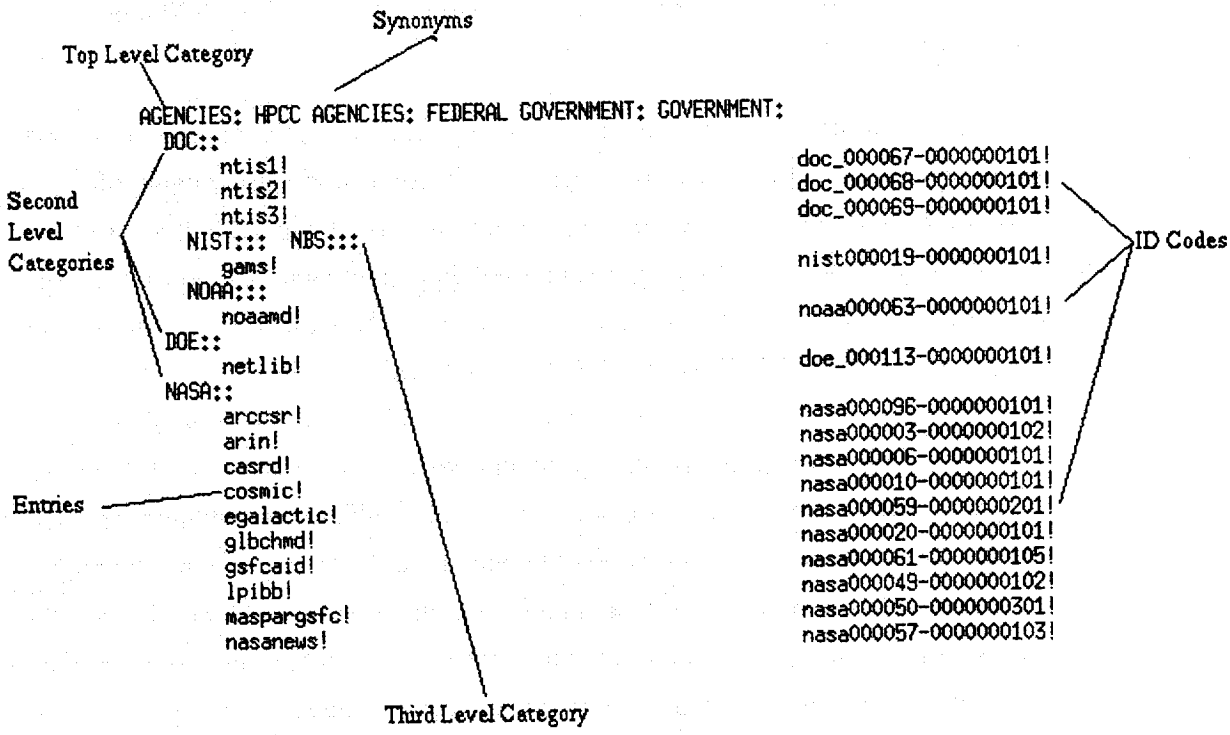

Figure 1

In Figure 1 the top-level category of *AGENCIES* is shown. *AGENCIES* is actually part of an organizational thesaurus. The prototype thesaurus includes several different types of categories in order to test the usefulness of thesauri based on things other than subject; in fact, the prototype thesaurus is not a thesaurus in the strictest sense of the term, but contains additional information as well (see [L] and Appendix B). Here we show a portion of the thesaurus augmented to includes id's and other formatting characters; this is the form used by the browsing tool to speed searching. *AGENCIES* also has the synonyms *HPCC AGENCIES*, *FEDERAL GOVERNMENT*, and *GOVERNMENT*. Immediately beneath *AGENCIES* are the more specific second-level categories *DOC*, *DOE*, and *NASA*; each of which is a particular agency of the Federal Government. *DOC* has two third-level categories, *NIST* and *NOAA*, both of which are divisions of the Department of Commerce. Finally the entries list that information which is actually available. Since *GAMS* is an entry under *NIST* which is under *DOC* which is under *AGEN-*

CIES, we know that GAMS is provided by the National Institute of Standards and Technology, a part of the Department of Commerce, which is an agency of the federal government.

One way of thinking of the thesaurus is as a collection of branches of a tree with general terms at the top and, beneath each general term, more specific terms. Beneath these terms are more specific terms until we get to id's for the items. A problem with this type of arrangement is that many of the referenced resources are too general and do not fit into a single category. For example, the anonymous ftp site `wuarchive.wustl.edu` contains information that is too diverse to be classified in this way. Instead what may be done is to classify specific sections of the information and provide pointers to the sections. Rather than just putting `wuarchive` in the thesaurus under *Operating Systems*, because there are several complete operating systems available from `wuarchive`, each operating system is entered individually, and a special ftp client is used that automatically goes to the right position in the `wuarchive` directory tree. This lets large archives be broken down into specific categories of information, and each category may be placed separately in the thesaurus.

Breaking down large information providers into many smaller ones is not always practical. Some gopher servers do not lend well to such a break. In these cases an entry for each type of information is made in the thesaurus, and it is left to the user to locate the specific information he or she wants in the archive.

The Browsing Tool

The hierarchical structure of the prototype thesaurus dictated the basic design of the sample browsing tool. By default it starts by displaying a list of the top-rank categories, and allows one to select those of interest. When a category is selected, its sub-categories are displayed beneath it. (See Figure 2.), and so on until the outermost branches and leaves of the tree have been reached. With this method one can quickly locate information if the entire classification is known. A problem with this type of search is that the thesaurus is ambiguous; it is not clear whether chemistry is a life science, a physical science, or both. Another problem with this type of search is expansibility; in a full thesaurus there may be hundreds of top-level categories, making locating the correct one difficult.

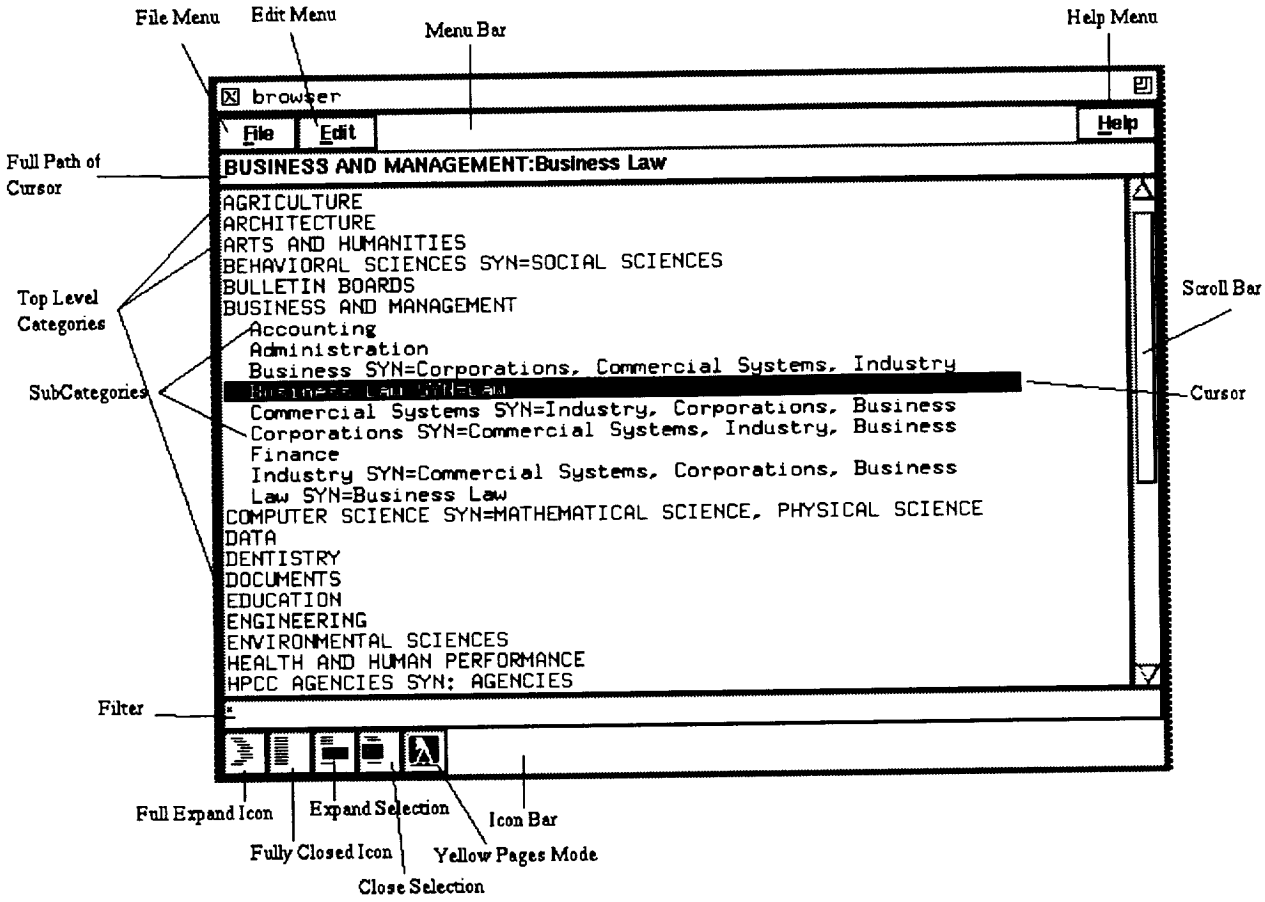

Figure 2

One feature of the sample browsing tool that helps one locate a specific entry in the library is the filter (See Figure 2.). Whenever a category is displayed, it is highlighted if it or one of its sub-categories matches the string in the filter. Exact matches are not necessary as the string uses a simple matching style often referred to as globbing.[14] When using globbing, the single character "?" matches any single character; the character "*" matches any number of characters and any string enclosed in square braces, "[" and "]", matches any single character in the string. The string in square brackets can be abbreviated by using a dash to stand for everything between two characters; i.e. "[a-f]" is the same as "[abcdef]". For example, the default filter of "*" matches everything. A filter of "a*" would match everything that begins with an "a". A filter of "?a*" would match everything whose second letter was an a, and "[a-fh]*" would match everything

[14] See the C-Shell manual page for a more complete discussion of globbing.

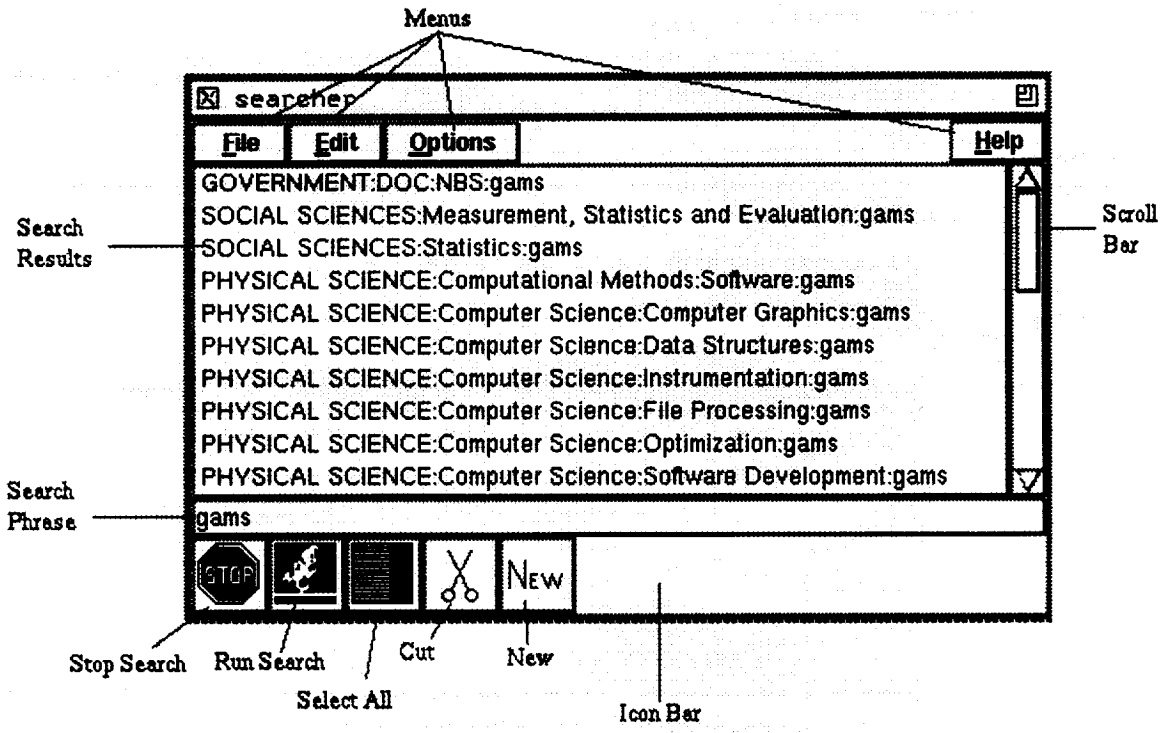

Figure 3

that started with either an "h" or any letter between "a" and "f" inclusive. The matching is also not case sensitive, so "A" matches "a".

The filter helps one locate an object when a part of the title or category is known. However it does not allow one to go directly to an object. A search tool was created to allow one to go directly to any entry in the thesaurus. This is done by specifying search strings that can be exact matches, globbing, or regular expressions.[15] A search for the term "gams" is shown in Figure 3. The search results are displayed in the central portion of the search tool. The top-rank category is shown at the left, followed by a colon, followed a sub-category, followed by a colon, and so forth until the matched string is displayed at the end of the line. This is the same format used for the full-path display at the top of the browsing

[15] See [WS] for a discussion of regular expressions.

tool (see Figure 2), for the save files (as explained below), and for the cut-and-paste features.

Working sets may also be maintained so that only relevant sections of the thesaurus are displayed. When searching for information related to mathematics, there may be no reason to display information about *HEALTH AND HUMAN PERFORMANCE*. A section of the thesaurus can be removed from view by highlighting it, and then selecting "Cut" from the **edit** menu. Entries may be added to the view by cutting and pasting between the different windows in the browser, or by using the **X** selection. When an appropriate view into the thesaurus has been constructed, selecting "Save" from the **file** menu saves the current view so that it may be loaded again at a later time. Several different views can be stored in different files and loaded as needed.

With the browsing tool, locating a specific topic becomes quite easy. For example, to locate information concerning wavelets, one could either search directly for "wavelets" and see in which categories it falls (if any), or progress through the ranks of the thesaurus by recognizing that wavelets involves numerical analysis, which in the thesaurus falls under *COMPUTER SCIENCE*. One then just clicks on *COMPUTER SCIENCE* and sees the sub-category *Numerical Analysis*. When once clicks on *Numerical Analysis* one sees *Wavelets*. Clicking on *Wavelets* will tell you that the University of South Carolina Mathematics Department offers some information on wavelets. Double clicking on that line will connect you to the wavelet archive at South Carolina. Hence finding information has been reduced to reading a few categories and clicking a few times.

Future Directions

The sample browsing tool is by no means complete; several extensions immediately come to mind. Perhaps the most extensible part of the browser is the search utility. One possible extension is to allow fuzzy searches. Fuzzy searches have the ability to match words which sound or are spelled similarly to the search term, making it possible to return correct results even when the search term has been misspelled. Synonym matching would be another useful search tool. This would allow strings to match if they had the same meaning, not just if they have

the same spelling. For example, if one is searching for information about cars, auto and automobiles would also be matched.

Another possible feature is to provide a way of moving between categories that are related by other indices. For example, an organizational index could be used to relate religion and multi-media email because information relevant to both is provided by the ftp archive `wuarchive.wustl.edu`. A simply way of moving from religion to multi-media email could be provided based on this link.

Another useful feature would be the ability to customize the thesaurus. Currently the browser can work on any thesaurus that is structured similarly to the prototype thesaurus. Particular views of the thesaurus can be saved and loaded; however, the browser provides no mechanism to alter the relationships of the categories. For example, in the prototype thesaurus *Chemistry* is under *LIFE SCIENECES*; a physical chemist may disagree with this classification scheme. Hence a method should be provided for a user to rearrange the classification according to individual preference.

Conclusion

The Internet provides a wealth of information, but has no real road maps for navigation. The Catalogue of Repositories in the HPCC Logical Library provides one method for locating information on the Internet via hierarchical thesauri and indexes. The browsing tool provides a way of navigating a thesaurus and accessing related information providers. It allows one to quickly find a specific piece of information while still allowing one to browse the stacks and see what is available.

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Appendix A. TCL/TK

The tool command language and associated X toolkit [O] was chosen for the development of a prototype browsing tool because implementing user interfaces in TCL/TK is simple and adding features does not require much code. For example, the following lines of code create a menu in TCL/TK.

```
1    menu .l.mf.f.m

2    .l.mf.f.m add command -label "New" -underline 0 -command
{list_new}
3    .l.mf.f.m add command -label "Save As" -underline 0 -command
{list_save}
4    .l.mf.f.m add command -label "Print" -underline 0 -command
{list_print}
5    .l.mf.f.m add command -label "Exec" -underline 0 -command
{list_exec}
6    .l.mf.f.m add separator
7    .l.mf.f.m add command -label "Close" -underline 0 -command {de-
stroy .l}

8    menubutton .l.mf.f -relief raised -text "File" -underline 0
                -menu .l.mf.f.m -bd 2 -width 6

9    pack append .l.mf .l.mf.f {left}
```

Line 1 creates a menu, and lines 2-7 each add one item to the menu. Line 8 creates the menu button use to access the menu. And Line 9 adds the menu button to the menu bar. The commands to be executed when the menu item is selected are created elsewhere (See Appendix C for a complete listing of the code.)

TCL does, however, have speed limitations; iterating through a 1500 item lists takes approximately half a second on a Sun 3/60 when no processing on the list elements is done. I.E. the TCL command:

```
foreach entry $list {}
```

executes in about half a second when list is a 1500 element list. Since many of the navigation aides in the browser require iterating throughout the entire thesaurus, which might be arbitrarily large, implementing those sections in TCL is not feasible. Therefore TCL was extended [O] to have some functions explicitly for dealing with the thesaurus. A new TCL data type was created similar to that used for files. These additional functions allow TCL to read in the database and

access its contents and implied relationships, as well as display a large portion of the database, and search the entire database.

Overall TCL/TK was an excellent choice for quickly prototyping a user interface for an application. and may be used as an extension language in the final implementation.

Appendix B Prototype Thesaurus

The prototype subject index for the HPCC Software Exchange Catalogue of Repositories (Repcat) is based upon a hierarchical set of controlled vocabulary (allowed search terms). The non-empty categories of the subject tree are listeed below in outline format, with the categories indented within their broader categories. The implicit root category of this tree is "SUBJECT INDEX," although for experimental purposes, the tree has acquired terms, such as FEDERAL GOVERNMENT, FOREIGN GOVERNMENTS, LIBRARIES, and UNIVERSITIES, that would be (and eventually will be) more properly incorporated in a distinct organization index. Synonyms for a given category are introduced by the symbol "SYN=" and are equivalent to the given category.

It is important to recognize the purpose of this subject index. In particular, it is not an index for finding individual books, articles, or software modules on the Internet. That is left to the specialized indexes, such as NIST's GAMS or NASA's Recon. The purpose of the subject index discussed here is to provide subject pointers to major repositories on the Internet; it operates at the granularity of libraries and databases, not of individual packages or documents.

Users of Repcat[16] will discover that the hierarchy of terms described here is also referred to as a "subject thesaurus." This is a harmless abuse of terminology in this context. Strictly speaking ([L]) a thesaurus is an alphabetically arranged listing of search terms containing codes pointing to a broader term (i.e., the category of next-higher rank above the given term), narrower terms (i.e., categories subordinate to the given term, and possibly codes pointing to related terms. A thesaurus is logically equivalent to an index tree such as the one described above.

The prototype hierarchy was initially derived from the bulletin of courses offered by the University of Maryland at College Park. The two highest ranks of categories were taken from the organization of the University into divisions and departments. Courses provided a third rank of subject terms. Inadequacies in this scheme were apparent from the start, but the effort by the university to structure itself based on a reasoned classification of knowledge, provided a useful starting point for a subject index. Unfortunately, there are many instances of courses for which the HPCC Logical Library has no holdings, and conversely, there are repositories in the library for which the universities courses are inadequately structured to act as a classification scheme. For example, entries for general reference and organizations were added. Thus the prototype thesaurus has been under continual revision and refinement as varous kinds of repositories have been added to the library; it is by no means a finished product.

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[16] Repcat may be accessed through the HPCC Logical Library by telnetting to `hypatia.gsfc.nasa.gov` and logging in as hpcc.

It is useful to think of the protoype subject hierarchy in the following way. First, the successive stages of its development provide progressively more complete and accurate subject pointers to the various libraries and repositories accessible from Repcat, and this process of improvement will continue. Second, the development of the hierarchy has led to the creation of software to ease the process of revising the thesaurus as new references are added to the library and experience dictates improvements. Third, actual use of the resulting subject index has stimulated development of a powerful index-browsing tool that allows a user to easily find thesaurus entries pointing to subjects of interest and then to access repositories on the Internet that contain related materials.

The thesaurus tree shown here in outline form is a subset of the current master thesaurus. Only those terms for which the library contains pointers to actual repositories on the Internet are included here.

AGRICULTURE
ARCHITECTURE
ARTS AND HUMANITIES
  Art History and Archeology
    Renaissance Art
  Art
    Galleries
  History
    Histroy of Science
BEHAVIORAL SCIENCES, SYN= SOCIAL SCIENCES
  Anthropology
  Economics
  Geography and Regional Science
  Measurement, Statistics and Evaluation
  Science Policy, SYN= Technology Policy, SYN= Public Policy
  Statistics
BULLETIN BOARDS
BUSINESSES AND MANAGEMENT
  Business, SYN= Corporations, SYN= Commercial Systems, SYN= Industry
COMPUTER SCIENCE, SYN= MATHEMATICAL SCIENCE, SYN= PHYSICAL SCIENCE
  Aeronautics
  Applied Mathematics, SYN= Numerical Analysis, SYN= Computational Methods
    Wavelets
  Astronomy
  Astrophysics, SYN= Space Science
    Extra-Galactic Astronomy
    Solar System
  Computer Science

- Artificial Intelligence
- Computer Algorithms
  - Software
- Computer Graphics
  - Images
- Data Communications
  - Security
- Data Encryption and Security
- Data Structures
- Error Handling, SYN= Instrumentation
- Fault Tolerant Systems
- File Processing
- Operating Systems
- Optimization
- Parallel algorithms
- Programming Languages
- Software Design, SYN= Software Development
- Supercomputing, SYN= High-performance computing
- Window Systems

Geology
- Paleontology

Mathematics
- Algebraic Topology
- Analysis, SYN= Calculus
- Calculus of Variations
- Complex Analysis
- Discrete Math
- Dynamic Systems, SYN= Nonlinear Dynamics, SYN= Chaos
- Generalized Functions, SYN= Integral Transforms
- Geometry
- Linear algebra, SYN= Matrix Theory
- Number Theory
- Ordinary Differential Equations
- Partial Differential Equations
- Stochastic Processes
- Wavelets

Oceanography

Operations Research
- Discrete Systems Simulation
- Numerical Methods in Operations Research
- Queuing Theory
- Stochastic Models

Physics
- Nuclear Theory

- Space Science
- Statistics

COMPUTERS
- Amiga
  - unix
- Books
- CoCo
- IbmPC
  - Ms Windows ver. 3
  - MsDos
  - unix
- Mac
- MultiMedia
  - mail
- Sinclair
- Unix
- Vax
  - vms

EDUCATION
- Higher Education
- Secondary Education

ENGINEERING
- Aerospace Engineering
- Civil Engineering
  - Designs to Resist Natural Hazards- Earthquakes
  - Forestry
- Electrical Engineering
  - Digital Communication
  - Digital Image Processing
  - Digital Signal Processing Techniques

ENTERTAINMENT, SYN= GAMES

ENVIRONMENTAL SCIENCES
- Environmental and Resource Policy
- Meteorology
- Natural Resources Management Program

FEDERAL GOVERNMENT
- CIA
- Department of Education
- DOC
  - NIST, SYN= NBS
  - NOAA
- DOD
- DOE
- EPA

HPCC Program, SYN= High Performance Computing and Communtications Program
Library of Congress
NASA
NIH
NSF
USDA
FOREIGN GOVERNMENTS
European Community
INTERNET TOOLS, SYN= INTERNET
Bulletin Boards
ftp
Gopher
Mail
Resources
JOURNALS, SYN= REPORTS, SYN= MAGAZINES, SYN= NEWSLETTERS
LAW
Communications
LIBRARIES, SYN= LIBRARY SCIENCE
Library Aides, SYN= Bibliographics
Catalogues, SYN= Online Public Access Catalogues, SYN= OPACS
Internet Library Tools
Publishers
LIFE SCIENCES
Biochemistry and Molecular Biology
Cellular Biology
Computational Biology
Biological Sciences
Ecology
Evolution
Genetics
Botany
Chemistry
Genetics
Physiology
MEDICINE
History of Medicine
Pharmacology
Radiological Sciences
MUSEUMS, SYN= GALLERIES, SYN= EXHIBITS
NEW ACQUISITIONS
REFERENCE
UNIVERSITIES
California Institute of Technology

Carnegie_Mellon
GA Tech
Metropolitan State University, Minnesota
Univeristy of Minnesota
University of Delware
University of North Carolina
University of North Texas
Washington University, St. Louis